Virtual sensing power electronics

Traction inverter case

NEWTWEN

Customer background

The customer power electronics' team was in search of a solution to:

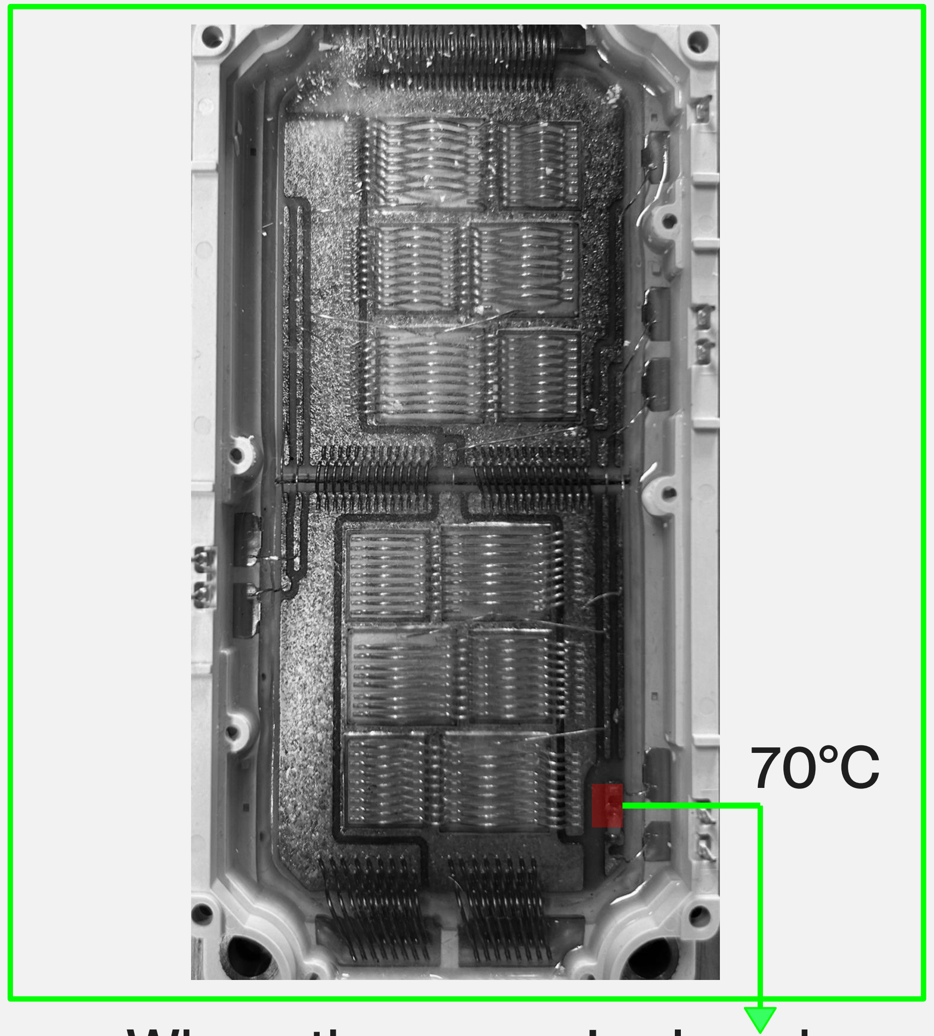
1. Increase the nominal performance of their traction inverter

2. Decrease the Billing of Material of the components

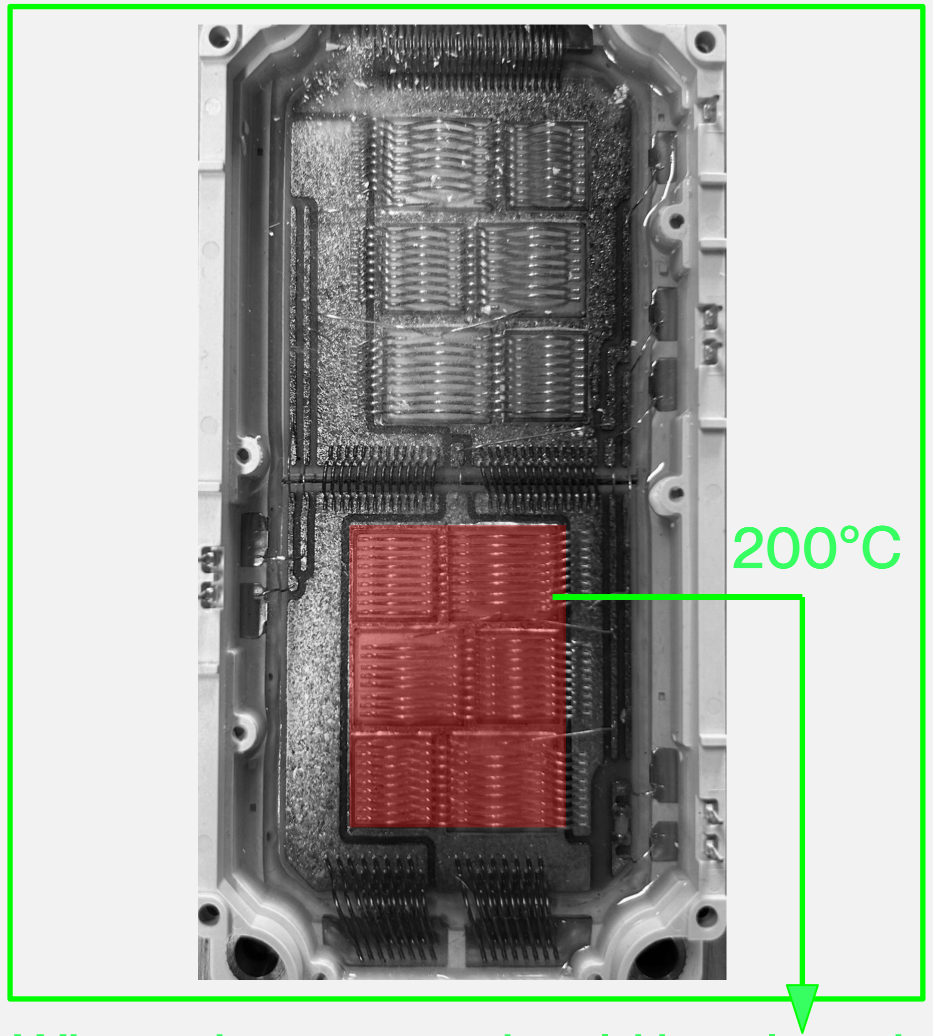
Problem statement reframed

Thermal Management & Control

The thermal management of today's power modules **operates in total blindness**, leaving it blind to real-time conditions. This lack of insight forces the implementation of **oversized safety margins**, ultimately **sacrificing the performance, efficiency and profits** of cutting-edge deep-tech devices, valued in the market with current capacity (1 A ~ 1 $).



Where the sensor is placed



Where the sensor should be placed

Virtual thermal sensors

VTS Impact

Virtual thermal sensors–based control KPI:

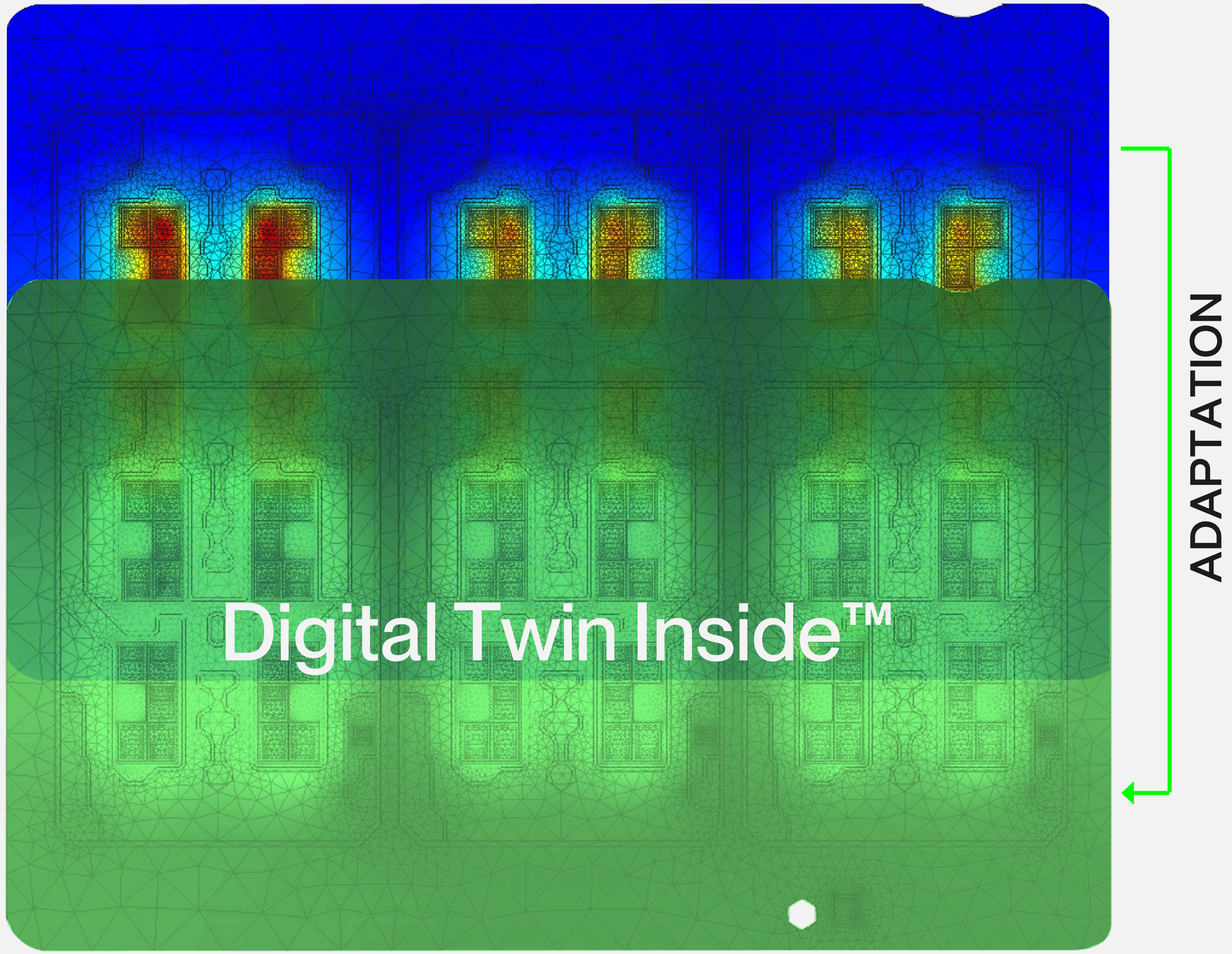
- 5°C safety margin thanks to high model reliability (Previous customer margin was 25°C)
- 10% increased nominal current from the inverter
- 4x improved peak current duration
- Enhanced junction condition monitoring to improve the lifetime of the device

Virtual thermal sensors explained

Virtual Thermal Sensors

A **real-time software solution** with **no sensing placement limitations**, capable of **predicting future outcomes** to optimize control decisions.
Embedded directly in the control unit, virtual thermal sensors replace and enhance traditional hardware sensors with unprecedented flexibility and intelligence.

Real device thermal analysys

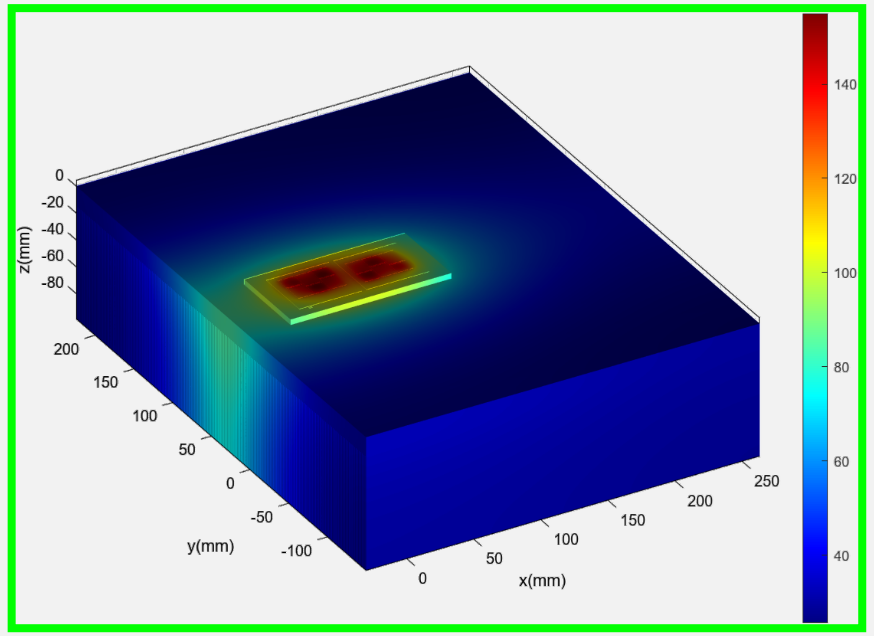


Virtual thermal sensors methodology

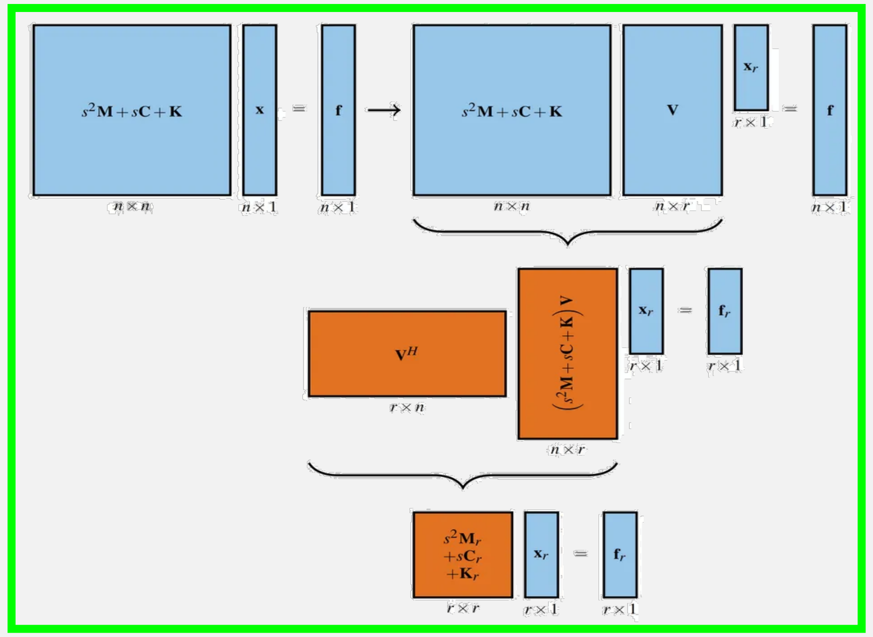
Methodology

Input
CAD, material properties and power module datasheet

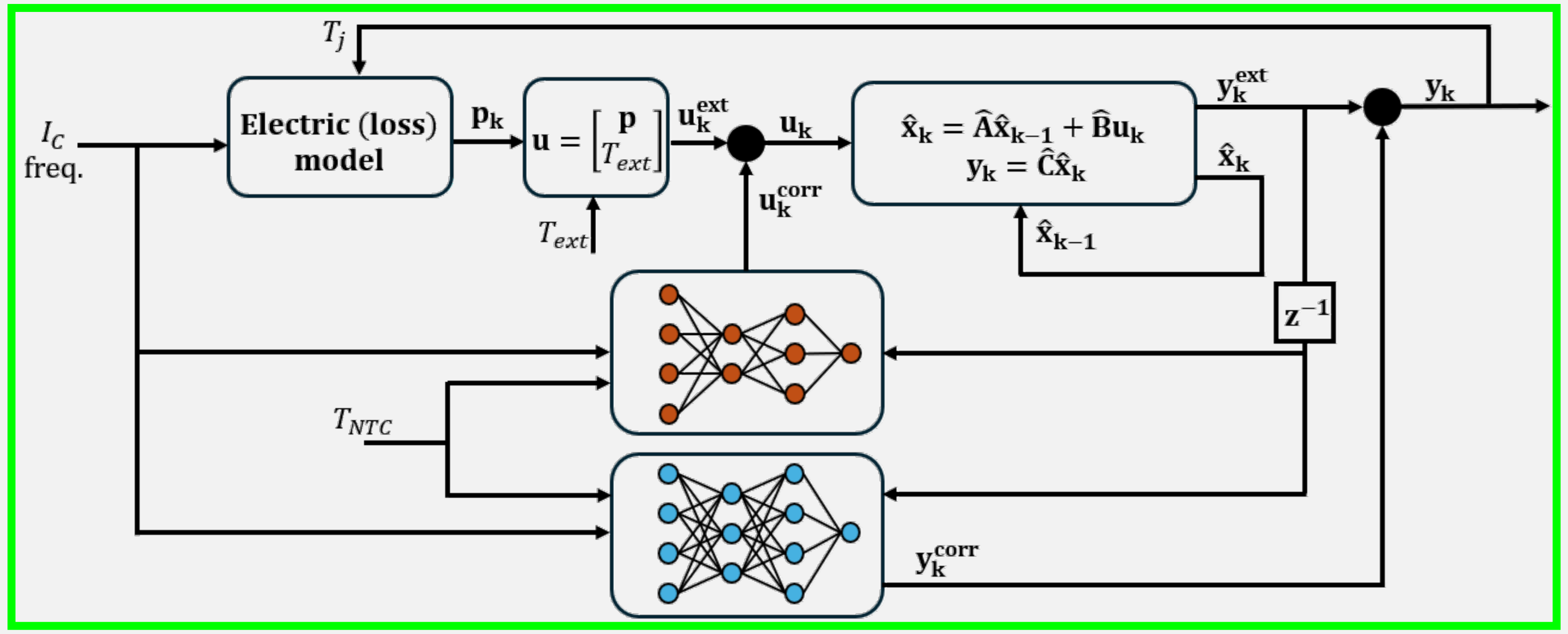
Input
Data from real devices



Finite element analysis (FEA)
~ 1 milion of degrees of freedom (DOF)



Model order reduction (MOR)
From 1 milion DOF to just 24 DOF



Physics AI virtual sensors
Calibration with real sensor measurements

Output
Final software architecture to be embedded into third party platforms

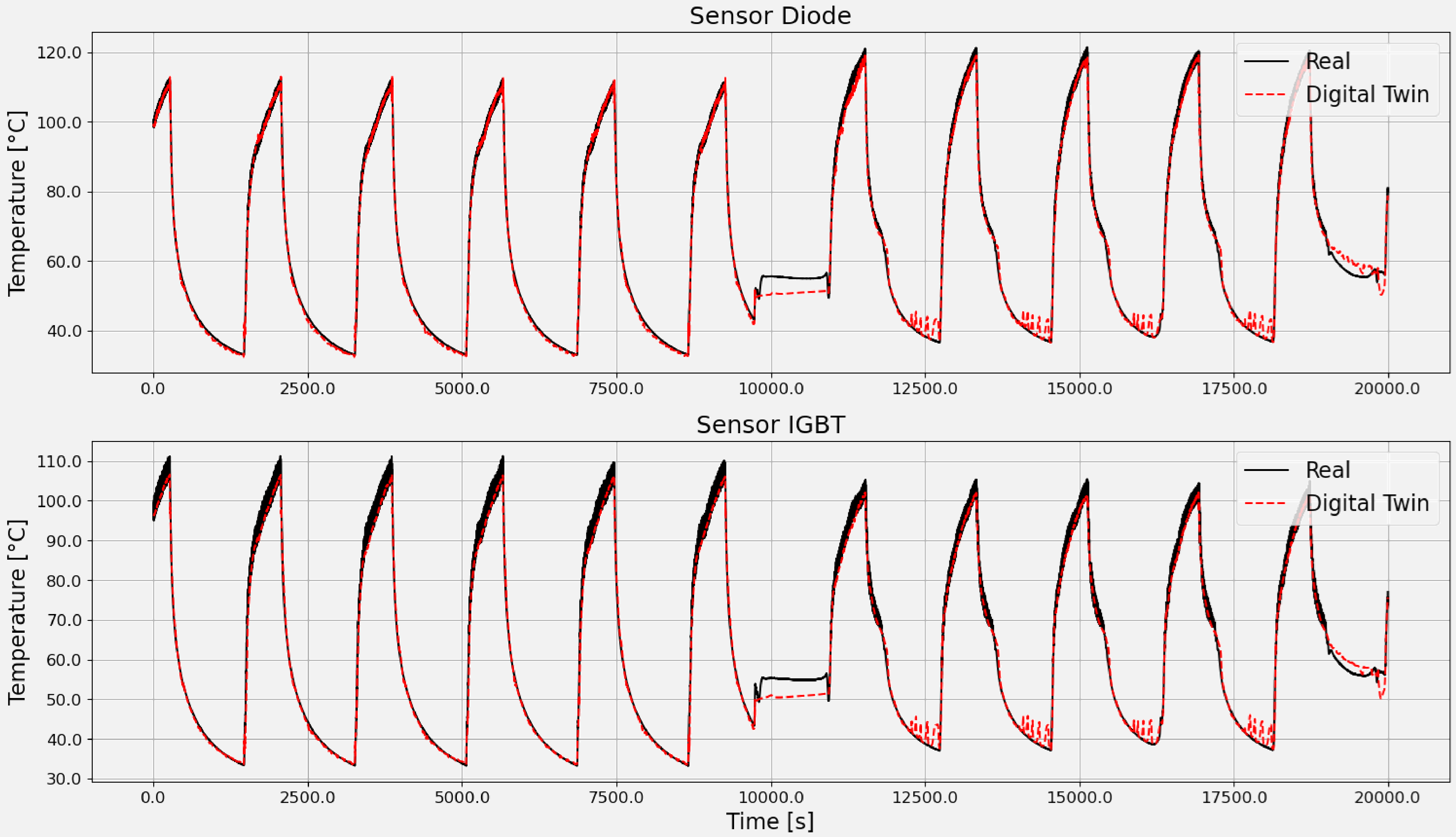
Technical KPIs

Customer Requirements

1. IGBT semiconductor junction points temperature predictions (transistors and diodes).
2. Delta (Real sensor to virtual sensor) prediction $< \pm 5$ °C in transient and steady state for all the operating conditions (current, switching frequency, voltage, coolant flowrate, and coolant temperature) of the inverter in the entire lifecycle and for 2 different samples.
3. Model size for control unit < 5 kB of RAM and <100 kB of FLASH as target.

Results

Drive7 starting life



Diode error statistics

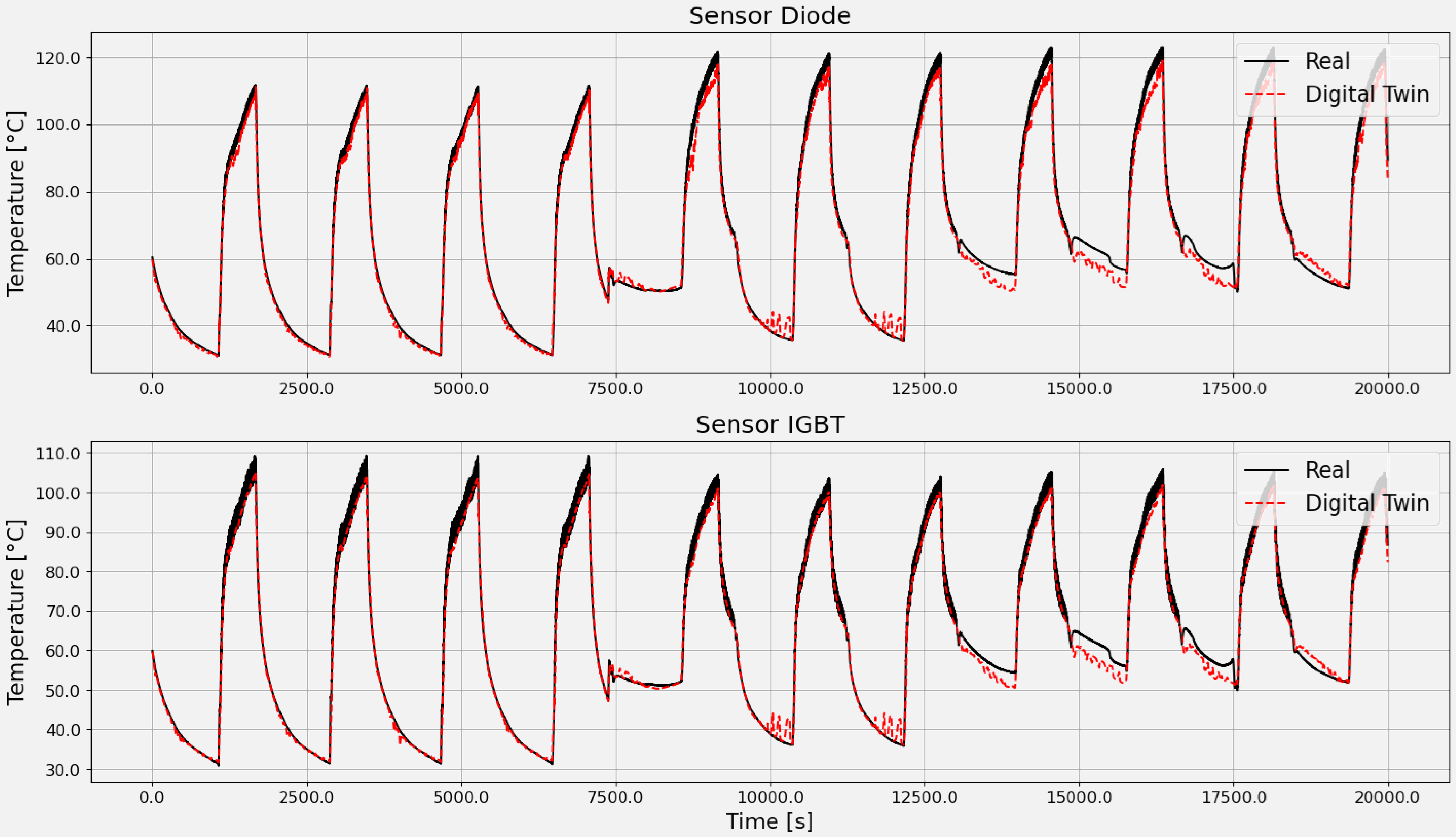
Mean: 1.5428389310836792
Std: 1.3937206268310547
Median: 0.9863853454589844
95th percentile: 4.506984710693359

IGBT error statistics

Mean: 1.5058835744857788
Std: 1.470281720161438
Median: 0.9635391235351562
95th percentile: 4.538116455078125

Results

Drive7 end life



Diode error statistics

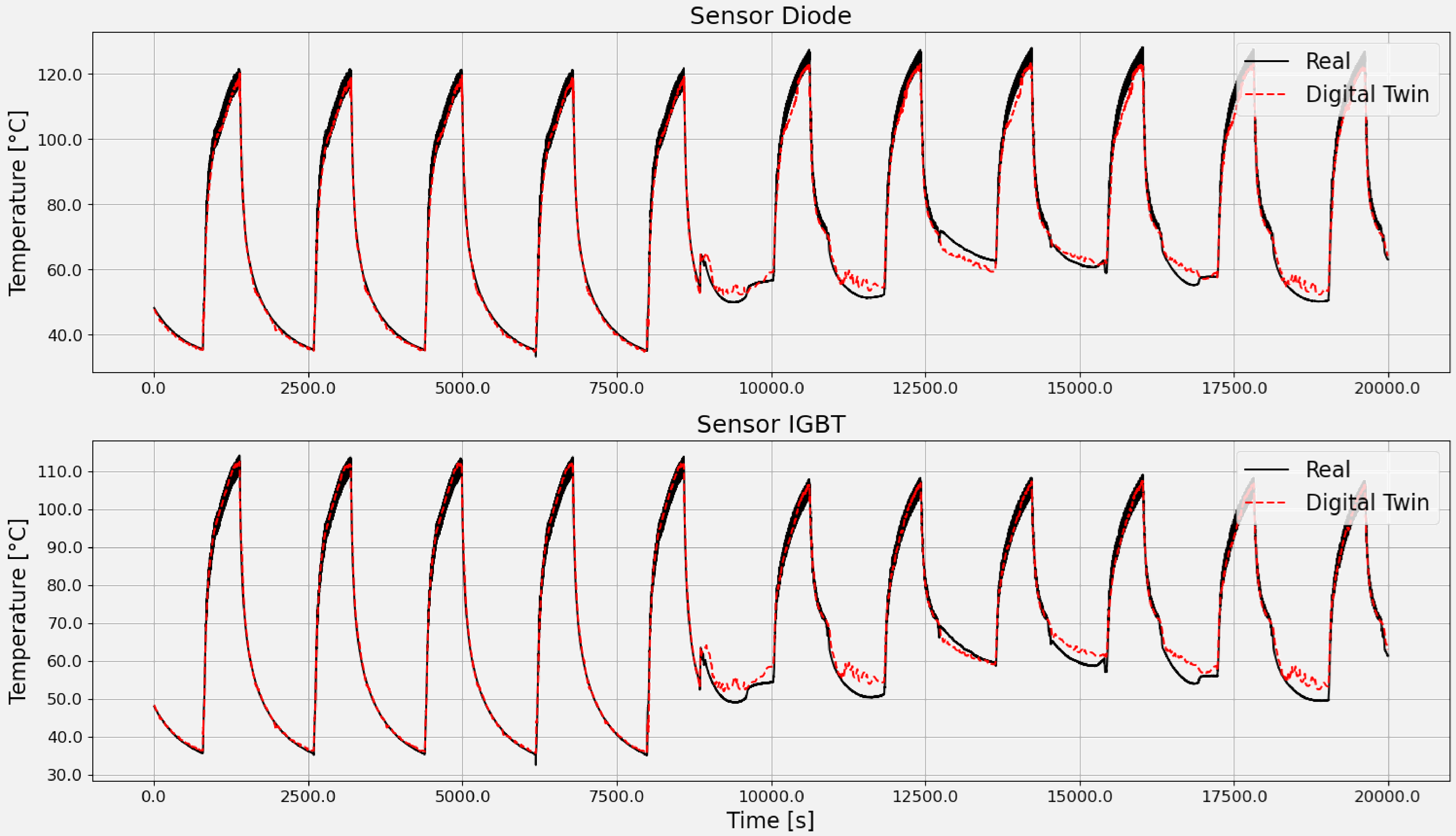
Mean: 2.1885597705841064
Std: 1.828560471534729
Median: 1.6682548522949219
95th percentile: 5.726509094238281

IGBT error statistics

Mean: 1.650015115737915
Std: 1.515903830528259\3
Median: 1.1723098754882812
95th percentile: 4.630645751953125

Results

Drive8 starting life



Diode error statistics

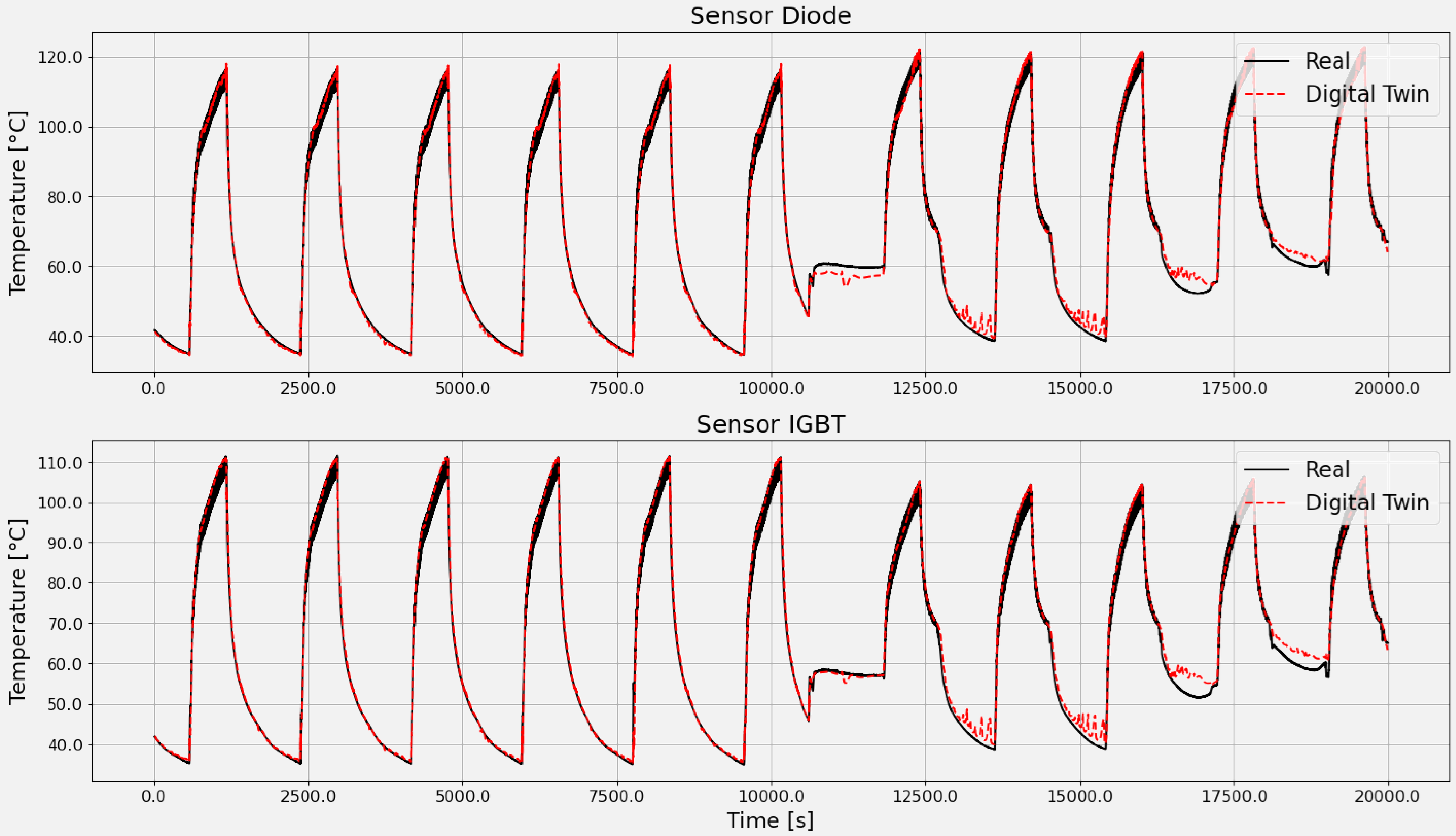
Mean: 2.5252909660339355
Std: 1.966353356521606
Median: 2.084228515625
95th percentile: 6.43487548828125

IGBT error statistics

Mean: 1.6584278345108032
Std: 1.320032000541687
Median: 1.3110504150390625
95th percentile: 4.121513366699219

Results

Drive8 end life



Diode error statistics

Mean: 1.6080474853515625
Std: 1.4334560632705688
Median: 1.0917205810546875
95th percentile: 4.492984771728516

IGBT error statistics

Mean: 1.469383716583252
Std: 1.4060449600219727
Median: 0.9641342163085938
95th percentile: 4.269779205322266

Impact on control

Implementation

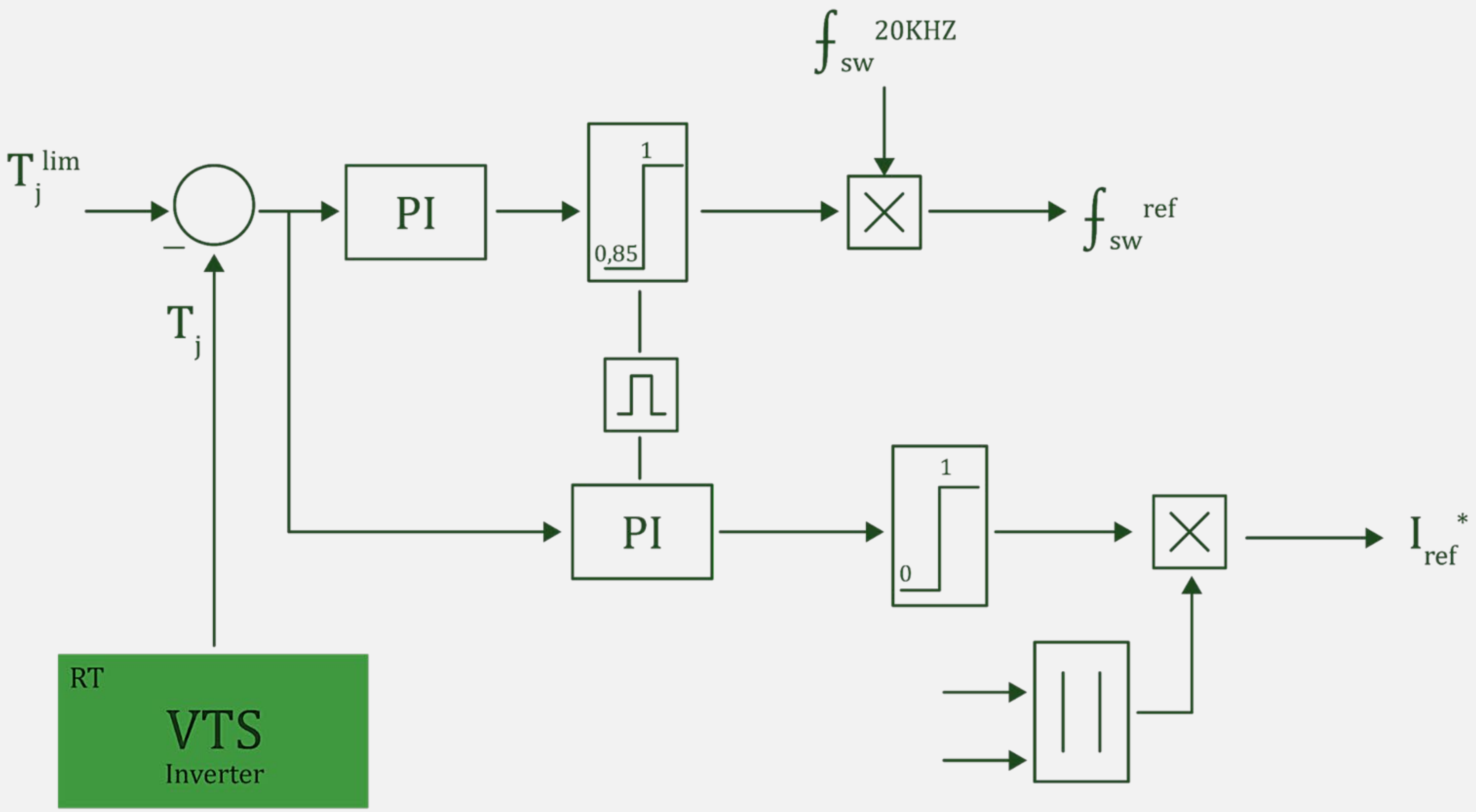
Digital Twin in real-time:

- Flash: 10kB (5 kB for the models and 5kB for source file)
- RAM: <1kB
- Execution time 36 us in Aurix TC3

Implementation

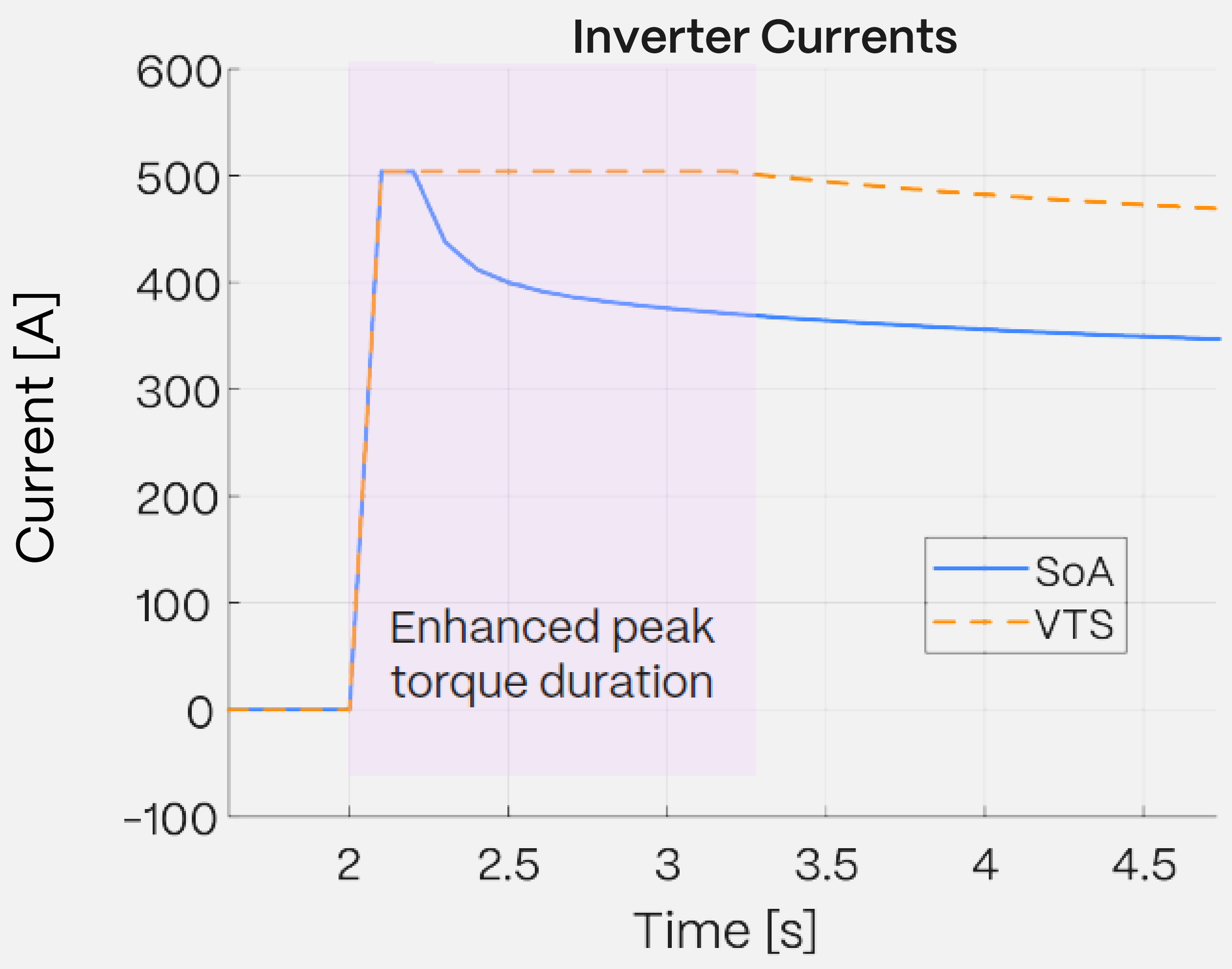
Digital Twin in real-time:

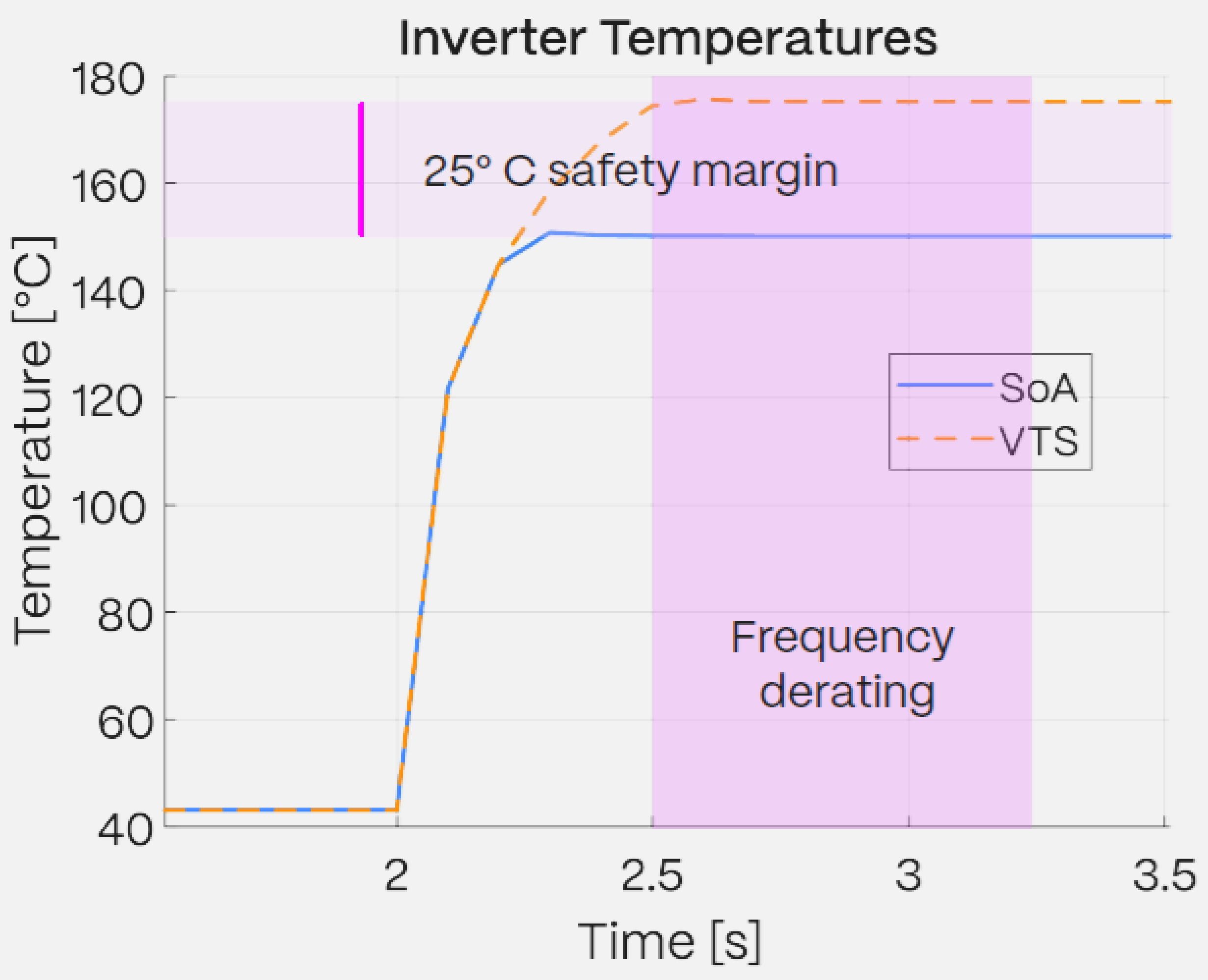
Derating strategy limiting first the switching frequency and then the output current based on junction temperature estimation from the digital twin reducing the safety margins to 5°C



Implementation

Safety margin reduction effect



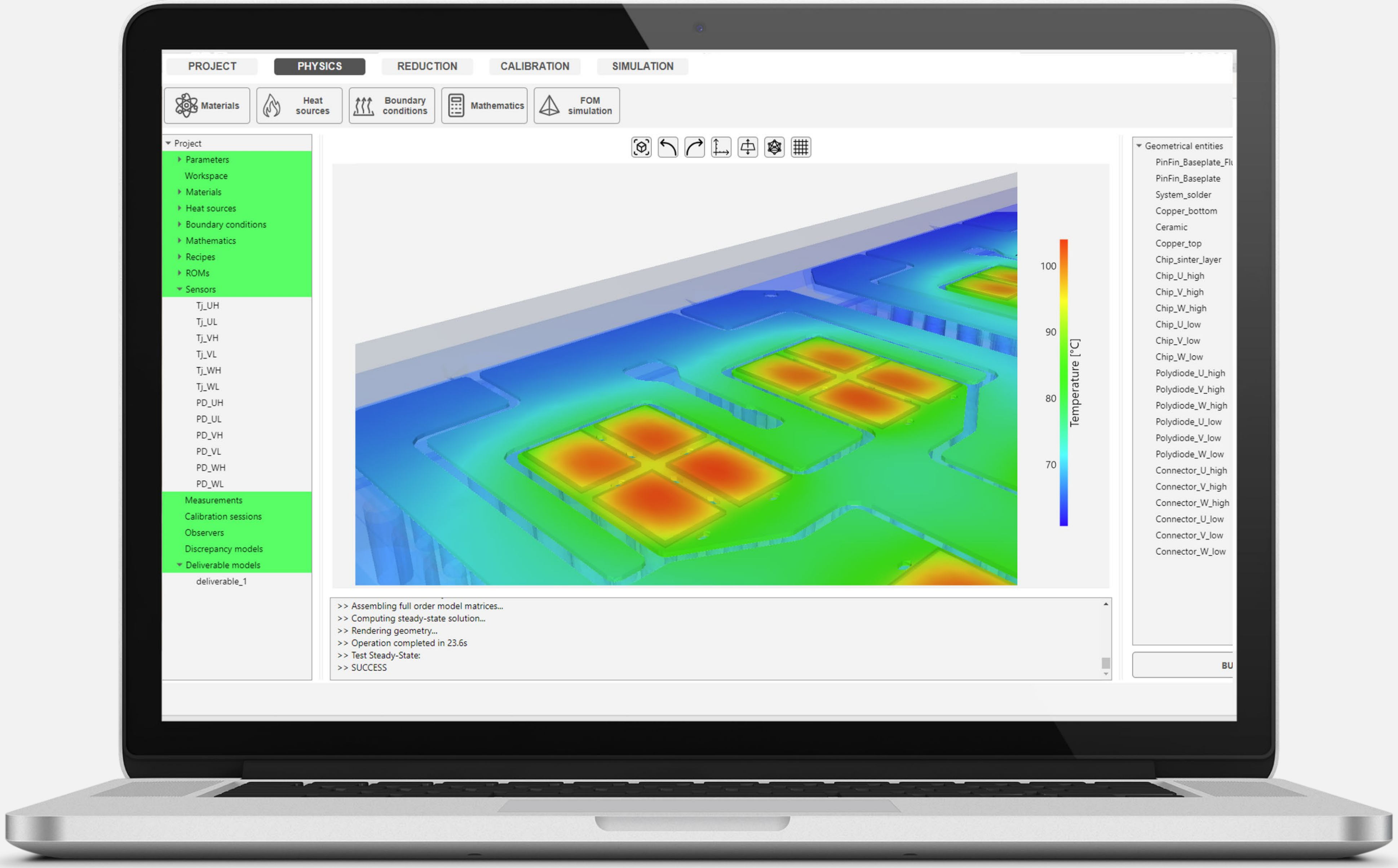


Tooling

Twin Fabrica

The entire project has been carried out with Twin Fabrica, Newtwen engineering software platform to create and deploy **virtual sensors** with the **streamline methodology reviewed above**:

1. Import your geometry
2. Make multiphysics simulation
3. Get reduced order model (ROM)
4. Import your real data measurement
5. Empower your ROM with AI
6. Export you virtual sensing setup



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